Electric Vehicles Are the Future:
Or Do They Have Too Much Baggage to Fly?

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John Thomson
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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

Signature: John Thomson Date: May 10, 2023

Approved: Travis Elliott, Department of Engineering and Society Date: May 10, 2023

Introduction

The purpose of my Science, Technology, and Society (STS) topic is to critically examine the advantages and disadvantages of EVs through research, comparisons, and calculations. Energy is the most essential resource on our planet. In regards to Science, Technology, and Society, energy fuels all three topics. With global population growth, developing countries, and an increasing reliance on transportation, energy demand is ever increasing. Society broadly assumes that "clean" sources of energy such as wind, solar, and nuclear energy along with energy storage systems such as lithium-ion batteries are the solution to the many environmental challenges caused by fossil fuel energy production. The common assumption, rarely questioned, is that "energy sources (wind, solar, tidal, wave, nuclear, etc.) and energy storage *must* increase quickly (Dehghani-Sanij et al., 2019)." One of the largest contributors to both energy demand and consumption is transportation. In an effort to make transportation less harmful to the environment, electric vehicles show promise in being the technology that will ultimately replace petrol powered, internal combustion engine vehicles. Electric vehicles (EVs) utilize batteries in order to power their emission-free engines. EV batteries are charged via power grids, which are powered by a combination of energy production methods: natural gas, coal, nuclear, hydro, wind, solar, and others. Given their ability to be charged by any energy source, emission-free electric vehicles are one of the most suitable approaches to minimizing the use of internal combustion engine vehicles (ICEVs). However, the negative environmental impacts of batteries found in EVs pose major challenges as global battery storage capacity increases (Kucevic et al., 2020). Clear environmental disadvantages of battery storage include an excessive carbon footprint from production and primary use, full life-cycle inefficiencies of batteries, and lack of viable battery recycling methods. Therefore, this study aims to shed light on the potential disadvantages of

EVs, ensuring a comprehensive understanding of their environmental implications. While it is valuable to view the actors involved in the discourse surrounding electric vehicles (EVs) through the lens of the Actor-Network Theory (ANT) framework, this paper's analysis will not extensively employ ANT. However, recognizing the network of actors and their interactions within this broader context can provide valuable insights into the complexities and dynamics of the EV landscape.

Greenhouse Gas Emissions

Climate change poses a significant challenge in the global environmental landscape. Climate change refers to the complex alterations in global temperature trends and atmospheric conditions. Global warming, the anthropogenic increase in Earth's average surface temperature, is a prominent manifestation of ongoing climate change. Global warming is caused by greenhouse gases (GHGs), emitted gases that trap heat in the atmosphere. In the US, greenhouse gas emissions are composed of carbon dioxide (79%), methane (11%), nitrous oxide (7%), and fluorinated gases (3%). In 2020, the US emitted a total of 5,981 million metric tons of CO2 equivalent in greenhouse gases (US EPA). Carbon dioxide, predominantly emitted through the combustion of fossil fuels, waste incineration, and biological processes, serves as a key benchmark for comparing EVs and ICEVs. Therefore, carbon dioxide output will be the leading metric used in this paper to evaluate the various environmental impacts of EVs and their alternatives.

In addition to using carbon dioxide emissions as the main metric, most data backing this paper will be sourced from the EPA, the United States Environmental Protection Agency. The EPA provides a luxurious amount of accessible and comprehensive data which allows for simple calculations and comparisons. While this excludes data from all other countries, direct findings from this data set can be generalized and extrapolated globally.

Diving back into the discussion of the massive amount of carbon dioxide emitted in the US, the EPA reports that the transportation sector is responsible for 33% of carbon dioxide emissions, which is higher than any other energy use sector. Of the entire transportation sector, light-duty vehicles make up 57% of GHG emissions (US EPA, 2015). "Light-duty vehicles" refers to cars with a gross vehicle weight rating less than 8,500 pounds– the vehicles that most Americans drive every day. The fact that light-duty vehicles are the leading emitter of GHGs among the leading sector of US carbon emission underscores the critical importance of electric vehicles. In order to assess electric vehicles' potential to reduce carbon emissions when compared to internal combustion engine vehicles, it is essential to conduct direct calculations between the two.

Head-to-Head: EVs versus ICEVs

Often heard in the debate between electric and gas vehicles is that electric vehicles have zero emissions which must make them the clear winner. Contrarily, also heard is that the energy used to produce and power EVs is not carbon free and actually exceeds the carbon production caused by ICEVs. Without directly comparing data and diving into specifics, it is hard to determine which side of the argument is right. To investigate this argument, I will compare two light-duty vehicles (one electric and one gas) head-to-head with real world data. For the electric car, I selected the best-selling electric car of 2022: the Tesla Model Y. The Model Y is Tesla's mid-size vehicle that starts at $54,990, has a range of 330 miles, and does 0-60 mph in 4.8 seconds. The Model Y is by no means a "budget" car, and therefore I will compare it to a gas car with a similar price, capacity, and performance. There are numerous cars with similar specs to the Model Y, but I decided to pick the number one ranked luxury midsize car by U.S. News & World Report: the Mercedes- Benz E-class sedan. The E-class has many trims and engine options, but the base model starts at $56,750, has a range of around 420 miles, and does 0-60 mph in 6.1 seconds. Calculating carbon emissions of these two vehicles based on various factors and EPA data will provide an answer to the debate between electric and gas in terms of carbon emissions per mile driven. As EVs operate without tailpipe emissions, the GHG emissions per mile from driving the Tesla are attributed to the electricity consumed for battery charging. Energy sources used to power America's electrical grid vary depending on geographical location, as certain regions of the US use a far higher percentage of renewable energy to power their grid than other regions. Given that, EPA's source for fuel economy information, fueleconomy.gov, states that the Tesla Model Y outputs 110 g/mi of CO2 based on the average US electricity mix. In contrast to the Tesla, the GHG emissions from the Mercedes originate from the vehicle itself, independent of the operational region. According to the Environmental Certificate of the Mercedes-Benz E-Class, the E-Class sedan emits 227 g/mi of CO2. The carbon output per mile of the Mercedes is more than double the output of the Tesla charged by the average US power grid. This disparity is notable; however, it is important to note that these values do not encompass the CO2 emissions associated with the manufacturing process of the vehicles. The production of lithium-ion batteries necessitates a substantial amount of energy, encompassing resource extraction, transportation, and battery manufacturing stages. Specific GHG emissions of battery production will be further discussed later in this paper, but for the sake of simple calculations, I will use an estimated value of carbon emissions per kWh of battery produced. According to the "Analysis of the climate impact of lithium-ion batteries and how to measure it," a study from the Circular Energy Storage research firm, it takes 73 kg of CO2 to produce one kilowatt-hour of lithium-ion battery (Melin, n.d.). Multiplying that value by 81 kWh (the battery capacity of the Model Y) yields the total amount of carbon emissions from producing the Tesla's battery: a staggering 5,193 kg of CO2. Assuming that the CO2 emissions from producing the rest of the Tesla is equal to the production of the Mercedes, the Tesla starts out with an additional 5,193 kg of CO2 emitted over the Mercedes. If both cars are driven 13,476 miles per year (The national average according to the Federal Highway Administration), it would take about 3.3 years for the Mercedes to exceed the carbon footprint of the Tesla (*Average Annual Miles per Driver by Age Group*, n.d.). Given the average vehicle ownership of approximately 8 years or 200,000 miles, it is highly likely that the Mercedes's emissions will exceed the Tesla's emissions over this duration.

This head-to-head compared two similar cars, with the EV being charged with the average grid electricity mix. What would happen if one stacked all the odds against an EV? What would the results be if the "dirtiest" EV, charged via pure coal, is compared to the most fuel efficient ICEV? To explore this scenario, I utilized Climobil, an interactive application that facilitates a similar EV-ICEV comparison to that presented in this paper. Comparing the EV with the highest production pollution, the Porsche Taycan Turbo S, charged with 100% coal electricity against the most fuel-efficient ICEV, the Hyundai Elantra, the Porsche is cleaner after 175,000 miles (*Climobil*, n.d.). Even under the most extreme analysis, the EV exhibits lower carbon emissions that the ICEV throughout its probable lifespan.

Battery Production

The head-to-head comparison of the Tesla and Mercedes would lean further towards the EV side of the argument if production of the battery didn't use such a considerable amount of energy. The mining, transportation, and actual production of batteries are energy intensive activities, and when compared to similar practices in the oil industry, lack economies of scale and efficiency. With increasing consumer demand and multiple car manufacturers planning to phase out their ICEV inventory, the World Bank estimates that lithium needs to be mined at five times the current rate to meet global climate targets by 2050 (Hund et al., n.d.). Lithium is typically extracted from brine deposits or hard-rock mineral deposits. Mining brine deposits first requires pumping brine into reservoirs followed by repeated cycles of evaporating off the water and treating the lithium salts left behind. The evaporation and treatment process is continuously repeated until the lithium concentration is high enough for further processing. Mining lithium from hard-rock mineral deposits involves mining, crushing, grinding, and roasting the ore. These two techniques of extracting lithium from our planet emit exuberant amounts of GHGs into the atmosphere. According to a journal article examining the lifecycle analysis of lithium mining, the "Cradle to Delivery Gate" of lithium mining emits roughly 5-20 tons of CO2 per *singular* ton of lithium compound (Kelly et al., 2021). Unfortunately, GHG emissions related to batteries do not cease once lithium is mined. As previously mentioned in the head-to-head analysis, actual production of batteries (converting lithium carbonate compounds into usable battery cells) requires additional energy which of course emits an excessive amount of GHGs. The general process of battery production starts with upgrading the mined raw materials into "battery-grade" materials using additional materials and energy. Using the battery-grade materials, battery cell components such as the cathode, anode, electrolyte, and cell container are made. Following component production is cell production, the actual assembling of components into a complete cell. This three-step production method requires heavily controlled climates: ambient temperature ranges, maximum allowed air contaminant parts per million, and maximum allowed humidity levels (Xu et al., 2022). This paper's life cycle analysis estimates GHG emissions per kWh battery cell production to be 53- 85 kg CO2 per kWh. That number is astronomically high when compared to coal-fired plants, which emit just 1kg/ 1kWh instead (Kebede et al., 2022).

This overview of battery production hopefully provides follow up context of why EVs start "behind" their ICEV opponents in terms of GHG emissions. In the head-to-head comparison between the Tesla and Mercedes, the Tesla had to be driven roughly three years to offset its initial "upstream" emissions. While EVs produce less emissions in their lifespan compared to their ICEV counterparts, future progress in minimizing the carbon footprint of battery production could considerably extend their lead. Potential tactics of reducing GHG emissions during the production of batteries largely relies on a) sourcing energy from renewables rather than fossil fuels and b) expanding battery production infrastructure to improve efficiency and facilitate economies of scale.

Battery Recycling

The costs from a financial and environmental perspective of making batteries are evidently high, making battery recycling quite sensical. Furthermore, recycling of batteries is crucial considering the natural materials required for battery production are non-renewable. According to an analysis of Lithium-ion battery recycling, "the estimated 500,000 tons of batteries which could be recycled from global production in 2019, 15,000 tons of aluminum, 35,000 tons of phosphorus, 45,000 tons of copper, 60,000 tons of cobalt, 75,000 tons of lithium, and 90,000 tons of iron could be recovered (Baum et al., 2022)." Unfortunately, the recycling of Li-ion batteries is extremely limited, and has become a vital issue for the future (Dehghani-Sanij et al., 2019). The current industrial recycling methods of batteries, 66% of which occurs in China, are pyrometallurgy and hydrometallurgical treatments. Pyrometallurgy recycling uses high temperatures to recover metals from spent batteries while hydrometallurgy recycling uses chemical treatments. These two methods of recycling are just two of many methods, all of which possess multiple challenges: time, money, technology, environment, and safety. Expanding the recycling infrastructure worldwide will take significant time, especially considering that some recycling technologies are not yet viable for large scale use. From the economic perspective, "The construction of a typical recycling plant has been estimated to exceed US$3 million including the land requirement, machinery, utilities, and labor (Makwarimba et al., 2022)." In addition to high upfront costs of constructing recycling plants, it is currently cheaper to obtain lithium via mining than it is from recycling. Government policies and incentives must intervene in order to make recycling a more economically viable business model. The more tangible challenges with battery recycling are the environmental and safety factors associated with recycling. There will always be concerns with the transportation, storage, and processing of large amounts of batteries, given their hazardous ability to explode. All recycling techniques use large amounts of energy, which of course emits more carbon into the atmosphere. In addition to air pollution however, it has been reported that wastewater from open loop recycling facilities have also polluted soil and water.

Recycling batteries is not only uncommon and costly, but enforcement is nearly non-existent. Simply put, "Lax controls and enforcement and inadequate facilities in many places cause major environmental and health problems (Dehghani-Sanij et al., 2019)." Recycling of batteries is a huge challenge, and will need to be addressed to combat the increased demand for energy storage.

Additional Concerns

Electric vehicles have different environmental impacts than traditional internal combustion engine vehicles, whether from the perspective of production, use-case, or recycling. Up to this point, this paper has evaluated the pros and cons of EVs primarily in terms of their carbon emissions. However, given that this paper is intended to address STS topics (Science, Technology, and Society), it is important to consider the societal impact of EVs, specifically the advantages and disadvantages for consumers. Focusing solely on the environmental effects EVs would leave out an imperative aspect of the discussion.

One of the clear disadvantages of EV ownership is the cost compared to ICEVs. In the head-to-head analysis of the Tesla and Mercedes, the Tesla Model Y was picked due to it being the best-selling EV on the US market today. With a price tag starting at $54,990, the Model Y can be considered an expensive, luxury vehicle. According to U.S. News and World Report, the two most sold light-duty vehicles are the Toyota Camry and Toyota Corolla, which start at $25,395 and $20,175 respectively. Given these prices, a hypothetical family in the market for a car could purchase a Camry *and* a Corolla for roughly $10,000 less than just the Model Y. Consumers who purchase EVs must also have a convenient place to charge their car, or spend around $2,000 dollars to have a charger installed in their home. When looking at income statistics of the average EV owner, CNBC reports that more than 70% of electric car owners have an income greater than $100,000, more than triple the average income in the US. While this information suggests that EVs are only practical for high-income individuals or families, there are more affordable ways of owning an EV. In the United States the cheapest electric car is the Chevrolet Bolt EV, which starts at $25,600. While the Bolt EV has less features, range, quality, and performance when compared to Tesla models, its price tag is direct evidence that some EVs are more affordable. Furthermore, the majority of EV consumers can expect to save considerable money from tax credits and cheaper refueling costs.

Even with relatively affordable options and potential financial benefits, many consumers are skeptical of EVs for reasons beyond cost. Those reasons largely include range anxiety and lifestyle changes. For car owners that are used to refilling their tank in a matter of minutes and hopping right back on the road, adjusting to EV transportation might be difficult. Even with DC fast charging, which is only available at commercial charging stations, it can take up to an hour to fully charge a car. For long distance commutes, re-charging adds significant time to commuting duration. Beyond charging time and adjusting one's lifestyle to such phenomenon, there exist another source of EV skepticism: range anxiety. Range anxiety refers to a driver's fear that their EV might not have enough driving range to reach desired destinations. Battery performance can drop with exceedingly high or low temperatures, making range estimates less accurate than that of a gasoline car. Additionally, some destinations might be completely inaccessible to certain EVs if charging stations are not available or close enough to the destination. According to a study on range anxiety, "the experience of owning an EV greatly influences range anxiety (Pevec et al., 2020)." This study suggests that increasing EV range and charging station prevalence will lower overall range anxiety, and hopefully sway reluctant, potential EV buyers.

Conclusion

This paper has analyzed the most important characteristics of electric vehicles within the context of Science, Technology, and Society. While skepticism and valid concerns arise due to the environmental impact of battery production, lifecycle inefficiencies, and inadequate recycling methods, it is crucial to recognize the overall advantages that EVs provide in terms of reducing greenhouse gas emissions and decreasing reliance on fossil fuels. Perhaps the most notable advantage of EVs is their lower carbon emissions per mile when compared to internal combustion engine vehicles. This reduction in emissions is a significant factor in mitigating the impact of transportation on climate change. On the other hand, it is essential to acknowledge that improvements are needed in the mining, production, and recycling processes of batteries to further minimize the environmental footprint of EVs. The cost of electric vehicles has been a concern for some consumers, but the availability of affordable options and government incentives, such as tax credits, makes EV ownership more accessible. These financial incentives not only make electric vehicles a more viable option for a broader range of consumers but also encourage the transition towards a more sustainable transportation system.

Though the application of the Actor-Network Theory framework is not a central aspect of this paper’s analysis, acknowledging the presence of diverse actors, such as climate change, production methods, and battery recycling provides a valuable lens to understand the complexities of the EV landscape. In summary, the future of transportation should continue to prioritize the development and adoption of EVs over ICEVs, while emphasizing research and innovation to address the challenges they currently face. By improving battery technology, energy production methods, and recycling processes, we can minimize the negative impacts of EVs as we enhance their benefits. Society must actively engage in ongoing conversations to question broad assumptions surrounding "clean" energy sources and storage systems, as well as thoroughly evaluate the social and technical implications of emerging technologies. Through these efforts, our planet can work towards a more sustainable and environmentally responsible future for the transportation sector and beyond.

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